5G Solutions for European Citizens

D4.8-D4.3C: LL performance evaluation and lessons learned v3

Document Summary Information

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Version	Issue Date	% Complete[1]	Changes	Contributor(s)
V0.1	05/12/2022	0	Initial Deliverable Structure	IRIS
V0.2	05/01/2023	30	Use Case Content Update	IRIS GLANBIA P&G ORBIS NTNU TNOR
V0.3	13/01/2023	95	Use Case Content update	IRIS GLANBIA P&G ORBIS NTNU TNOR
V0.4	30/01/2023	100	Final peer review and submission	TIM

Disclaimer

[1] According to 5G Solutions Quality Assurance Process:
1 month after the Task started: Deliverable outline and structure
3 months before Deliverable's Due Date: 50% should be complete
2 months before Deliverable's Due Date: 80% should be complete
1 months before Deliverable's Due Date: close to 100%. At this stage it sent for review by 2 peer reviewers
Submission month: All required changes by Peer Reviewers have been applied, and goes for final review by the Quality Manager, before submitted

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
GW	Gateway
VM	Virtual Machine
WI-FI	Wireless Fidelity
TC	Test Case
UC	Use Case

1 Executive Summary

The following deliverable reports the findings and lessons learned of the LL1 UCs during the cycle 3 trials.

Specifically, the document focuses on:

- The qualitative analysis of the cycle 3 trials performed by LL1 use cases with respect to their architecture, deployment process and measured KPIs.
- Highlights in architecture from each use case, particularly from the KPI perspective to illustrate how current 5G capabilities can be leveraged for different applications in each use case.
- Next steps in case the use case has some plan post project to booster the learnings and the results achieved in the project.

2 Introduction

Following Cycle 3 completion, such document will focus on the summary and conclusions from each of the use case active till the end of the project, sharing from the industry perspective, which could be the possibilities of integrating 5G Technology in their use cases. Evaluation will be based on the possibility of each UC to provide:

- A detailed architecture and information flow diagram, including testbed components and software elements.
- Cross Domain Service Orchestrator (CDSO) and 5G facility orchestration requirements
- Visualization System (VS) requirements

The field trials implemented on Cycle 3 will be considered the last iteration in order to achieve the target KPI of each case study.

Summarizing, this deliverable is the baseline for the 5G field trials for LL1, by creating, the test setup and architecture, purpose of the tests, challenge and mitigation measures, and also the next steps of the field trials for the factories of the future vertical.

2.1 Mapping Projects' Outputs

Purpose of this section, is to map 5G Solutions Grand Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

Table 1 : Adherence to 5G-SOLUTIONS GA Deliverable & Tasks Descriptions

5G-SOLUTION Task	*Respective Document Charter*	*Justification*
Task 4.2 - Performance evaluation and lessons learned *The purpose of this task can be briefly described from the following three aspects. First of all, the performance of each use case will be evaluated,* *particularly from the KPI perspective to illustrate how current 5G capabilities can be leveraged for different applications in each use case. Secondly, according to the results received from each use case* *in every agile-based iteration, provide requirements and suggestions to further improve both functional and non-functional capabilities of 5G facilities.* *Following that, each use case will be further evaluated to reflect the latest improvement of the 5G infrastructure from the application perspective.* *This task will also provide and establish systematic feedback loops to WP1-WP3, for continuous refinement. Results will be analysed both quantitively and quantifiably.* *Conclusions and*	*LL1 field trials Cycle 3 implementation and results.* *Chapter 3 provides qualitative analysis of Cycle 3 trials.* *Deliverable 4.8-4.3C contains qualitative analysis of the Cycle 3 tests and potential plans post project if the use case decides to move on using 5G Technology.*	*All Use Cases except UC1.4 has run some experiments during Cycle 3, trying to improve KPI and business experience.*

recommendations will be drawn including recommendations for further trial validations. When possible, the impact of 5G deployment will be also analyzed so to potentially allow operators to evaluate their 5G network deployment scope, pattern and duration. Throughout the validation testing period, knowledge and findings will be documented in deliverable D4.3 together with evaluation reporting and impact assessment for the LL, and extracting lessons learned for internal dissemination among the consortium, capacity building and external dissemination as appropriate		
5G-SOLUTIONS Deliverable		
D4.3C LL1 performance evaluation and lessons learned (v3) reports per testing cycle, containing a critical evaluation and findings from the LL1, lessons learned, the degree the KPIs have been met and suggestions for improvements for potential future cycles post project.		

2.2 Deliverable Overview and Report Structure

Such deliverable has been defined in order to evaluate qualitatively the results of Cycle 3 trials, suggest lesson learned and recommendations to communicate findings with each of the use cases, to drive improvements during the implementation of each of the use cases. To this end, Section 3 of this deliverable will provide the description of the Cycle 3 trials performed during Cycle 3 for UC1.1, mainly since the other use case did not provided yet any information to include in the current deliverable.

3 LL1 Cycle 3 trials analysis of results, lessons learned & recommendations for Cycle 3 trials

3.1 UC1.1 (PGBS, IRIS)

The next points summarize qualitatively which has been the results of Cycle 3 trials for such a use case in comparison to the targeted KPI.

Moreover, a set of actions and recommendations are described in order to explain the potential scenario for such use case post project.

3.1.1 Qualitative analysis of the results of Cycle 3 (KPIs vs reference KPIs)

The following table describes the results reported in the previous Deliverable D4.5 and adds the comparison with the targeted result and a brief description in case the KPI has not reached the target result expected.

Table 2: KPI Measurements Qualitative Analysis UC 1.1

Reference Test Case #	KPI	Trial Target (Reference KPI Baseline using other technology)	Trial Result	In case the KPI has not been achieved, a brief description about it.
TC1- UC1.1	Downlink	Up to 1000 Mbps	297 Mbps	The performance of the 5G is lower than expected
	Uplink	Up to 1000 Mbps	123 Mbps	The performance of the 5G is lower than expected
TC2 - UC 1.1	Downlink	Up to 1000 Mbps	296 Mbps	The performance of the 5G is lower than expected
	Uplink	Up to 1000 Mbps	196 Mbps	The performance of the 5G is lower than expected
TC3 - UC 1.1	Downlink	Up to 1000 Mbps	271 Mbps	The performance of the 5G is lower than expected

	Uplink	Up to 1000 Mbps	67 Mbps	The performance of the 5G is lower than expected

3.1.2 Cycle 3 detailed architecture and integration with the testbed, orchestrator and visualization system

Architecture is the same as the one described in D4.5

3.1.3 Lessons learned from Cycle 3 trials and recommendations

Such use case is one of the most challenging of the Living Lab 1, given the specific product to be examined. A standard RGB camera cannot detect all the defects that have been recognized as harmful for the product quality, thus to detect with an acceptable tolerance the harmful defects, IRIS has conducted a series of experiment aimed to identify the technology that best suit the purpose. After a preliminary investigation the hyperspectral image analysis (HSI) and the multispectral image analysis (MSI) resulted to be the most promising. Specifically, hyperspectral analysis takes advantage of the information brought by the analysis of near infrared (NIR) and short-wave infrared (SWIR) wavelength that allow to get an insight on the chemical composition of the product and such identifying discontinuity in the chemical fingerprint that are typically correlated to the presence of a defect.

The multispectral technology instead, mixes the information coming from visible light with the information brought by other areas of the spectrum. This technique is typically used in case the elements to be detected are clearly marked by well-known colours, shapes, or other visible effects, and the information brought from the analysis of non-visible wavelength adds level of details that cannot be seen by a visual inspection.

The cameras used for hyperspectral or for multispectral analysis (in brief HSI cameras and MSI cameras) are complex devices composed by a sophisticated set of lenses with specific coating working as filters for the different wavelengths, a series of sensors built with CCD or CMOS technology, and a fast control electronic. These cameras typically analyse the image line by line and the output of the sensor is not a common matrix with 0-255 values as for commercial cameras but it is an array of arrays. It can be seen as a matrix that doesn't cover the image surface but just a line of 1 pixel of height and L pixels of length. Each element of this line has the value coming from the specific wavelengths (W) analysis. While the product moves in the camera field, a sequence (M) of these images (called frames) are generated creating a LxMxW cube called hypercube. Reading the hypercube in the LxM dimension for all possible W layers it is possible to have the image of the product at a specific wavelength W. Each hypercube takes a lot of data space and sending hypercubes requires a very high data transfer rate.

The main results from this cycle of testing is that using 5G and mm wave we have achieved much higher data transfer rates than we ever achieved before, and with this, we have demonstrated that 5G and mm wave can really enable the digital factories for the future, especially in challenging contexts where real time transfer of high volumes of data is critical.

KPI	Result
Data transfer rate	Average of 320 Mbps, uplink, from camera to analysis server, located 25 m away.
Latency	< 10 ms
Reliability	Data transfer rate and latency sustained over 5 days, 5 hours per day.

The reason we have not achieved larger rates (i.e. 1000 Mbps) is that all the equipment available is designed for working on a downlink mode, and for these cases in industry – where many devices are sending large volumes of data to a centralized server -- we need high data transfer rate on an uplink mode.

For future endeavors and as a potential continuation of work on time-critical-large volumes of data transfer in industrial contexts, we recommend a collaboration with equipment makers and designers to develop new equipment with the goal of maximizing uplink data rates.

Overall, this project has allowed a successful demonstration and proof of concept of what is possible in the industry and factories using 5G and mm wave.

It is important to stress the fact here that some experts have clearly indicated that this might have been one of the first attempts to use mm wave in an industrial context in Europe. We are very proud of leading , together with IRIS and CityMesh, one of the first demonstration of mm wave in the industry in Europe.

3.1.4 Planning for the use case Post Project

This project has allowed a successful demonstration and proof of concept of what is possible in the industry and factories using 5G and mm wave.

Two main challenges for this cycle of experiments have been faced:

1. Availability of mm wave equipment. There is no commercial equipment available in Europe. It has taken several months for Citymesh to get the right pieces of equipment for these tests, from specialized suppliers.
2. Configuration of the equipment. It has been found out that there is not much knowledge in Europe on how to configure equipment related to mm wave. We have not been able to find experts that could solve some of the configuration problems we have faced. In fact, it is important to highlight here that some experts have clearly indicated that this might have been one of the first attempts to use mm wave in an industrial context in Europe. We are very proud of leading, together with IRIS and CityMesh, one of the first demonstration of mm wave in the industry in Europe.

The reason we have not achieved larger rates (i.e. 1000 Mbps) is that all the equipment that is available in Europe is designed for working on a downlink mode, and for these cases in industry – where many devices are sending large volumes of data to a centralized server -- we need high data transfer rate on an uplink mode.

For future endeavours and as a potential continuation of work on time-critical-large volumes of data transfer in industrial contexts, we recommend a collaboration with equipment makers and designers to develop new equipment with the goal of maximizing uplink data rates.

3.2 UC1.2 (GLAN, OMES)

The next points summarize qualitatively which has been the results of Cycle 3 trials for such a use case in comparison to the targeted KPI.

As we finally reach the end of the project, we will summarize what we learned and the expectation for the future following up with the entire coverage of the Glanbia plant with the public 5G network and the replacement of existing sensors with 5G ready sensors.

3.2.1 Qualitative analysis of the results of Cycle 3 (KPIs vs reference KPIs)

TCs 1 and 2 offered a good benchmark to evaluate the possible performance of the connectivity in the Glanbia plant. Since the results seen in cycle 2 were nearly to be acceptable, the challenge for cycle 3 was to reach the targets with the Three public network.

TCs 5 to 7 provided instead indications on the reactivity and usability of the application in a real production environment.

- TC01: Baseline tests over Wi-Fi using networking tools such as iperf for conditioning and coverage tests.

Steps performed for the test:

Open network cell info
Verify that you are connected to the correct 5G node
Record RSRP, RSSI, RSRQ, RSSNR values, repeat from at least three different positions form the node
Open Hurricane Electric Network Tools
Run Ping to a preselected IP address, repeat at least 3 times
Run Traceroute to a preselected IP address, repeat at least 3 times

- TC02: Test wired connection between IIoT gateway and Kepware data collector.

Steps performed for the test:

Open Pinger
Run Ping to a preselected IP address, repeat at least 3 times
Open Ping1 Plotter
Run Ping to a preselected IP address, repeat at least 3 times

- TC05: Baseline tests over 5G using networking tools such as iperf for conditioning and coverage tests.

Steps performed for the test:

Open Network Cell Info
Verify that you are connected to the correct 5G node
Record RSRP, RSSI, RSRQ, RSSNR values, repeat from at least three different positions
Open Hurricane Electric Network Tool
Run Ping to a preselected IP address, repeat at least 3 times
Run Traceroute to a preselected IP address, repeat at least 3 times
Run Iperf 2 to Iperf 3 to a preselected server, repeat at least 3 times

- TC06: Test using IIoT gateway and generating traffic from the target sensor devices and handsets.

Steps performed for the test:

Open Network Cell Info
Verify that you are connected to the correct 5G node
Record RSRP, RSSI, RSRQ, RSSNR values, repeat from at least three different positions
Open Hurricane Electric Network Tool
Run Ping to a preselected IP address, repeat at least 3 times
Run Traceroute to a preselected IP address, repeat at least 3 times
Run Iperf 2 to Iperf 3 to a preselected server, repeat at least 3 times

TC07: Test 5G native, 5G gateway and 5G node.

Steps performed for the test:

Open the mobile application and navigate the home page
Record the latency

Table 3: KPI Measurements Qualitative Analysis UC 1.2

Reference Test Case #	KPI	Trial Result	Measurement Method
TC01- UC1.2	**Latency Avg**	**4 ms**	**Measure end-to-end Latency**
	Latency Std. Dev	**1 ms**	**Measure end-to-end Latency**
	RSRP	**-55 dBm**	**Measure spread signal**
	RSSI	**-79 dBm**	**Measure spread signal**
	RSRQ	**-6 dB**	**Measure spread signal**
	RSSNR	**45 dB**	**Measure spread signal**
	Packet Loss	**0 %**	**Measure from client**
TC02- UC1.2	**Latency Avg**	**0.237 ms**	**Measure end-to-end Latency**

	Latency Min	**0.1 ms**	**Measure end-to-end Latency**
	Packet Loss	**0 %**	**Measure from client**
	Jitter	**0 ms**	**Measure end-to-end Jitter**
TC05- UC1.2	**Packet Loss**	**0 %**	**Measure from client**
	Latency Avg	**4 ms**	**Measure end-to-end Latency**
	Latency Std. Dev	**1 ms**	**Measure end-to-end Latency**
	Throughput	**iperf UDP** **Download: 145.5 Mbps Upload: 15.7 Mbps** **iperf TCP** **Download:66.0 Mbps Upload: 12.4 Mbps**	**Measure Throughput per device**
	RSRP	**-55 dBm**	**Measure spread signal**
	RSSI	**-79 dBm**	**Measure spread signal**
	RSRQ	**-6 dB**	**Measure spread signal**
	RSSNR	**45 dB**	**Measure spread signal**
TC06- UC1.2	**Latency AVG**	**40 ms**	**Measure end-to-end Latency**
	Latency Std. Dev	**10 ms**	**Measure end-to-end Latency**
	RSRP		**Measure spread signal**

	RSSI		**Measure spread signal**
	RSRQ		**Measure spread signal**
	RSSNR		**Measure spread signal**
	Packet Loss		**Measure from client**
TC07- UC1.2	**API Latency**	**66 ms**	**Measure API latency**
	Rendering Latency	**880 ms**	**Measure rendering time**

Application KPIs ensure a basic usability of the mobile application, but they don't allow exploiting AR or similar technologies.

3.2.2 Cycle 3 detailed architecture and integration with the testbed, orchestrator and visualization system

The architecture for such Cycle is described in D4.5

3.2.3 Public 5G installation Design

The installation was built using Ericsson radio Dots model 4475. The Dots are tri band: B1, 3 & 78 ceiling mounted DOT, port 1 antenna pattern 4x4 MIMO, 100 MHz IBW, 4 x 24dBm (250mW)

Transmission back to the Three core network is via a microwave Tx link installed on the roof of the cheese plant.

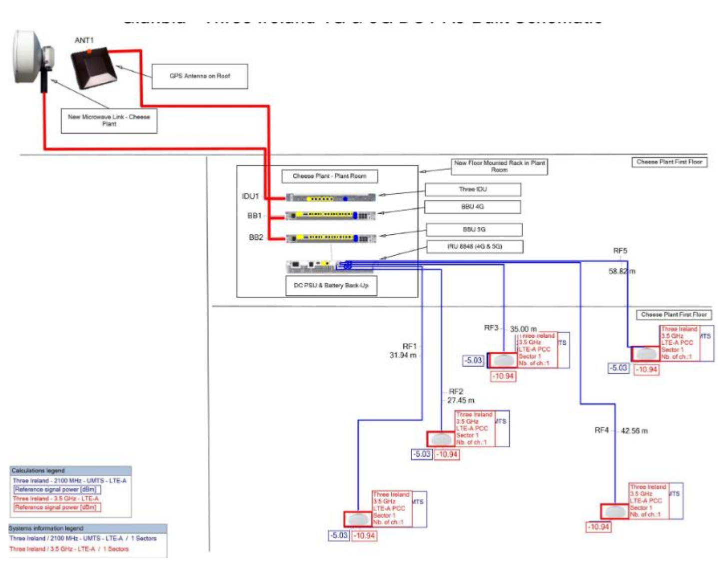

Figure 1: internal radio design

3.2.4 Test results from public 5G network

The results show that the public network performed better than the AMARISOFT node in in link speed, achieving more than 1Gbps download speed across the coverage area with upload speeds in excess of 46.5Mbps. The application latency, which is the best predictor of user experience, and which is represented by TC06 above, was comparable for both private and public installations.

4G Speedtests				5G Speedtests			
DOT	Download	Upload	Ping	DOT	Download	Upload	Ping
1	335 Mbps	13.2 Mbps	19 mS	1	1139 Mbps	49.1 Mbps	13 mS
2	315 Mbps	12.8 Mbps	17 mS	2	1172 Mbps	70.3 Mbps	11 mS
3	340 Mbps	16.2 Mbps	19 mS	3	1234 Mbps	53.2 Mbps	16 mS
4	295 Mbps	12.1 Mbps	19 mS	4	1201 Mbps	51.2 Mbps	16 mS
5	331 Mbps	10.1 Mbps	19 mS	5	1376 Mbps	46.4 Mbps	15 mS

Figure 2 public cellular 4G Vs. 5G

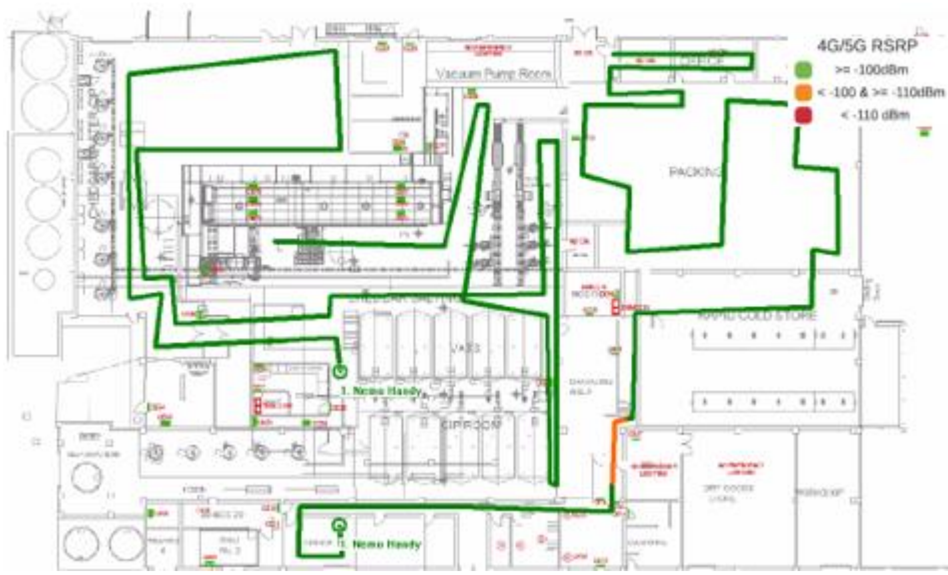

Figure 3 5G RSRP

3.2.5 Final Analysis

The Goal of UC1-2 was to demonstrate the potential of 5G as a viable alternative to Wi-Fi, 4G or other wireless technologies to deliver factory applications that DO NOT demand time critical communications. UC1-2 examined 2 scenarios with “non time critical” use case characteristics.

Scenario 1: **IIoT data collection.** Does 5G provide a viable alternative to existing wired, or other wireless, technologies to collect process data from hard to access factory locations?

Scenario 2: **The Connected Worker**. Does 5G offer advantages over existing wireless technologies when delivering mobile applications to the factory floor to enhance the efficiency of work processes?

3.2.5.1 Has the Goal been reached?

3.2.5.1.1 Technical Goal attainment conclusion

Scenario 1 Result: The technical measurements for network latency and link speed in the private node were sufficient to meet the modest IIoT requirements of the use case; statically deployed sensors in the factory space. However, due to the lack of native 5G enabled sensors or gateway nodes LoRA was used to simulate the actual data collection for this use case.

Scenario 2 Result: The technical measurements for network latency and link speed in both private and public 5G installations were sufficient to deliver to deliver a usable application experience to the connected worker for the work functions automated in the Use Case. Therefore, the technical goals of the connected worker use case were met.

3.2.5.1.2 Goal Business Value analysis

Result: Involvement in the Living Lab enabled the maintenance function to identify a practical business function to automate for initial testing in Cycle 2. The initial process described in Figure 7 is characterized by data duplication, manual data collection and extensive pre and post processing with their associated delays. The cycle 2 tests eliminated some manual activities; however, the end-to-end process was still characterized by extensive data transfer and local manipulation operations. In Cycle 3 all intermediate data manipulation was eliminated, and all actors carried out the required activities against a single centralized dataset.

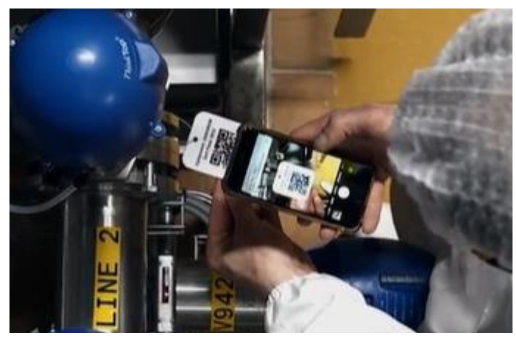

Figure 4 Connected Worker Valve Inspection

Use case evolution

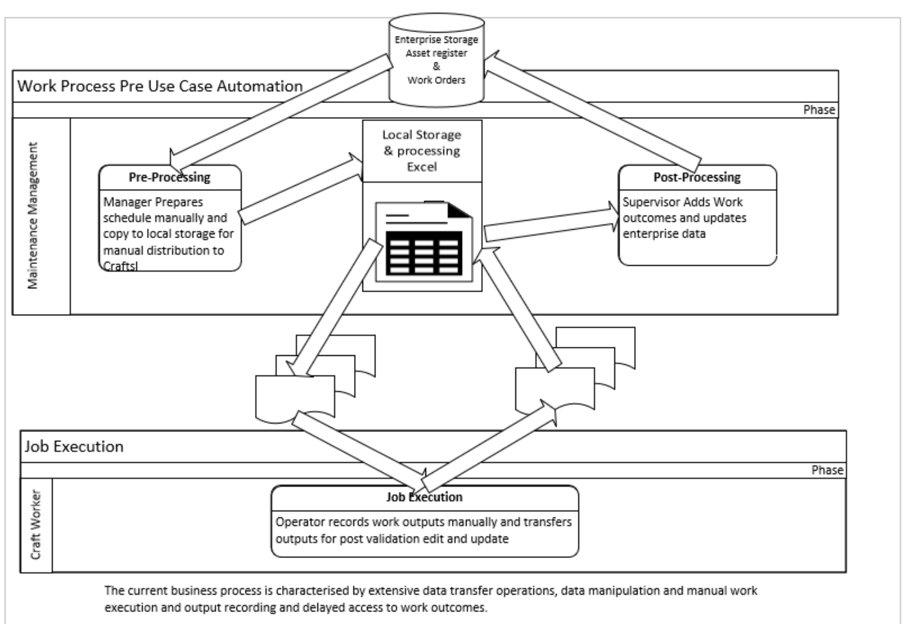

Figure 5 Initial Valve Overhaul Maintenance Process

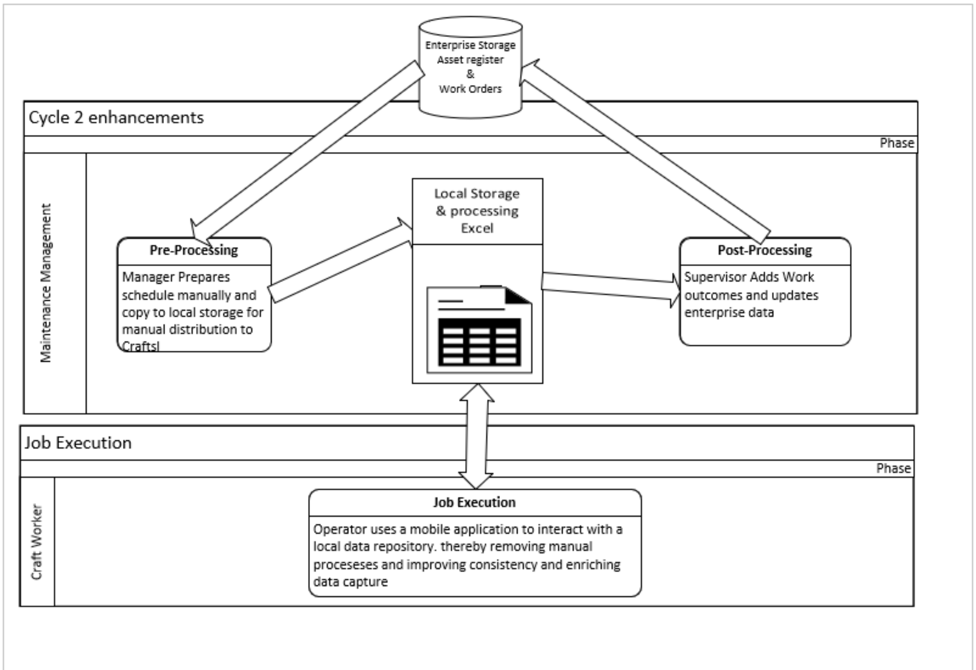

Figure 6 Cycle 2 Automated update of local data

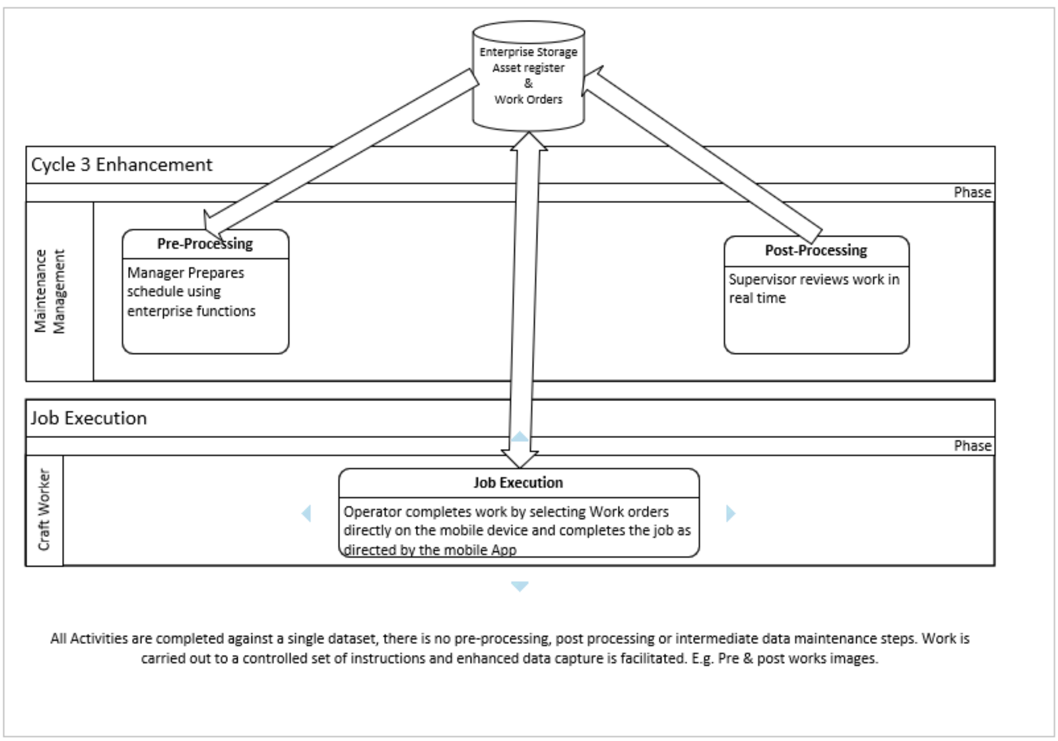

Figure 7 Cycle 3 Interaction with data centre services by connected worker

3.2.5.2 Can the Use case be exploited on a larger scale?

Scenario 1. IIoT. The IIoT requirement tested in this use case cannot be exploited on a larger scale until the native 5G infrastructure to support it becomes available. In addition, for this particular use case which is simple data collection from mainly static endpoints, existing technologies are likely to adequately meet the requirement. However existing technologies will not be able to meet the needs of IIoT use cases involving real time control and positioning of mobile assets or the type of Visual inspection system in UC1-1.

Scenario 2. Connected Worker. There are very few technical obstacles to using 5G to deploy Mobile connected worker applications on a larger scale. However, the there is a need to demonstrate credible total cost of ownership comparisons between Wi-Fi and cellular solutions that allow enterprise customers to make an informed technology choice.

3.2.5.3 Is 5G essential to the use case

For the connected worker application, the network performance demands of the application could possibly have been equally met by a well installed Wi-Fi network, however choosing 5G brings some key advantages.

- The installation uses the licensed spectrum of the operator making it less susceptible to interference.
- The assets requiring maintenance exist both inside and outside the facility; There is no additional work needed to provide outdoor coverage in areas already covered by the public network.
- The network planning installation and commissioning services provided by the Mobile operator demonstrated a key competence in this area that would be hard to replicate in an enterprise networking function tasked with deploying wi-fi, even in partnership with experienced network integration service companies.
- The post installation monitoring and management services of the cellular offering provide a higher level of assurance that the network will remain reliable. For instance, in the case of LL1, within hours of the installation completion the provider network operations centre was able to detect spectrum interference; this interference was from the Amarisoft node already operating in the plant.

The above observations during the course of LL1 UC1-2 demonstrate some clear advantages of cellular solutions over Wi-Fi. The argument for 5G over 4G is more difficult for the initial challenges presented by our use case and need us to think beyond the use case and to imagine some probable next steps. Our use case required us to generate and apply QR code tags to assets of interest in the plant. These were scanned by the mobile app and the relevant, asset status, work instruction or supporting documentation was retrieved by the mobile worker at the site of the asset. This tagging task, if extended across a large facility, is itself a significant undertaking. Using asset images coupled with precise positioning of the mobile device to identify the asset would facilitate rapid roll out of the solution and avoid this labelling exercise. 4G is unlikely to provide the positioning accuracy needed for this. Another extension of the use case needing the reliability and bandwidth promised by 5G would be virtual instrumentation whereby the connected worker would not only have access to static information about the asset but would also view and interact with real time information about the asset or nearby assets. Already available MES data points or indeed newly deployed wireless IIoT points would provide virtual instrumentation for the asset on an appropriate AR display.

3.2.5.4 Lessons learned from Cycle 3 trials and recommendations

Trials with the public 5G network allowed us to perform a comparison between the AMARISOFT node and the Three network. The comparison between the Private and Public approach has provided useful learnings for enterprise customers considering a technology investment in this area. The Three network is still evolving and the installation to support this use case was a non-standalone (NSA) extension of the existing public network. For our use case though the coverage of the private node was a key limiting factor in making a critical evaluation of the solution and this was a key driver for introducing a public 5G network for Cycle 3.

In addition to using a public 5G offering to improve coverage when reviewing previous tests with the key factory user groups it became obvious that we could add significant additional business value by eliminating middleware process steps and provide craft workers with direct access to the services they needed on the enterprise data platform in a data centre remote from the factory site so the connected worker use case was enhanced with additional capabilities and a second business function was accommodated.

Providing access to enterprise applications from factory floor locations often proves challenging. The difficulties arise from the physical characteristics of the location, the security requirements needed in the location to prevent unauthorized access and the different categories of users and endpoints which need access In the case of the data collection use case the private 5G offering providing a local secure service inside the factory to deliver that service has considerable merit and the security challenges of securing the service can be accommodated within the rules of common existing approved security configurations. However, providing access for the connected worker operating in the factory space to services outside the factory involves connecting the worker's device to the internal data network and routing this connection across multiple security perimeters. This proved complex in the context of our current security architecture. Conversely it proved far easier to provide a configuration that complied with enterprise architecture security policy policies by using a public 5G offering. In this case an air gap security perimeter was maintained between the user equipment and any aspect of the internal IT infrastructure.

Business learnings from the use case, and wider project involvement.

- New data collection channels using LoRA and MQTT were built to integrate "non-PLC" data into the time series historians which currently extract data from the plant using OPC via the PLCs over wired ethernet.
- It is possible to significantly enhance business workflows by avoiding data duplication and intermediate processing to ensure all participants in a business process act on a centralized data set.
- The tools exist today to extend enterprise applications to mobile workers operating in the factory space.
- A reliable communications framework is fundamental for shop floor digitalisation
- The technologies needed to support connected worker applications are available now.
- Cellular has significant advantages over Wi-Fi and other wireless technologies
- Public 5G offerings will be sufficient for many connected worker applications
- Private 5G presents a different set of technical and security challenges when integrating into an enterprise network.
- From participation in the wider 5G Solutions project we have learned about the potential evolution of our current application landscape into a future characterized by microservices delivered in a highly orchestrated mobile edge cloud (MEC).

3.2.3 Planning for the use case Post Project

Tactical

The project raised awareness of the possibility to extend the usage of the 5G technology more intensively in the future, especially to connect sensors and more in general equipment that are awkwardly reachable with a cable. We can continue to investigate this while we wait for the market to deliver native 5G sensor and gateway devices.

We can continue to develop the existing maintenance use cases to add further efficiencies to business workflows. Other opportunities like expert remote assistance are also within immediate reach using the technologies in its current state of development. The continuous improvement of the 5G network coverage and strength will ensure future success in the implementation of AR/VR, remote control and real time monitoring as outlined earlier. We await the commercial offerings from the mobile operators which will make the value proposition of this approach a better choice than the current default of Wi-Fi solutions.

Strategic

During LL 1 Cycle 3 Glanbia completed a Smart industry Readiness Evaluation using the Smart Industry readiness index (*SIRI). The purpose of the evaluation is to provide an organisation with a set of tools to evaluate where they are on their Industry 4.0 (I4) journey through a series of facilitated workshops with internal experts. Subject matter experts (SMEs) from manufacturing Operations, Quality, Supply Chain logistics, continuous Improvement finance and sales participated. The Assessment results provide a company specific prioritization matrix which helps identify the next most beneficial improvement steps along an industry 4.0 roadmap. The timing of the assessment, toward the end of the 5G Solutions project was not accidental the assessment recognized the business value opportunity identified and tested during the 5G solutions project but also helped position the potential of 5G in the context of an overall I4 journey and has helped to place communications at the heart of our I4 strategy.

**The Smart Industry Readiness Index (SIRI) was created in Singapore, in partnership with a network of leading technology companies, consultancy firms, and industry, and academic experts. SIRI comprises a suite of frameworks and tools to help manufacturers – regardless of size and industry – start, scale, and sustain their manufacturing transformation journeys. SIRI covers the three core elements of Industry 4.0: Process, Technology, and Organisation. Today, SIRI has been adopted internationally by both multinational corporations (MNCs) and small, medium enterprises (SMEs), with nearly 600 manufacturing companies across 30 different countries having completed the Official SIRI Assessment (OSA)*

**https://www.weforum.org/projects/global-smart-industry-readiness-index-initiative*

3.3 UC1.3/UC1.5 (NTNU, TNOR)

3.3.3 Qualitative analysis of the results of Cycle 3 (KPIs vs reference KPIs)

Table 4: KPI Measurements Qualitative Analysis UC 1.3/UC1.5

Reference Test Case #	KPI	Trial Target	Trial Result	Achieved	In case the KPI has not been achieved, a brief description about it.
TC1- UC1.3	UL Throughput	> 500 Mbps	66 Mbps	No	Telenor thinks it might be related to the limited allocated spectrum
TC2- UC1.3	DL Throughput	Order of Mbps	686 Mbps	Yes	
TC5- UC1.3	Latency	< 10 ms	21.8 ms	No	One reason might be the fact that the test facility is located 500km away from the core network, so the signal has to travel a long distance.
TC8 - UC1.3	Range	10m - 30m	Full coverage (See D4.2C)	Yes	
TC8 - UC1.3	Reliability	99.99%	100%	Yes	

3.3.4 Lessons learned from Cycle 3 trials and recommendations

Throughput

The achieved throughput is acceptable when it comes to downlink, but lacking when it comes to uplink. We have also observed that we get better throughput on the commercial 5G. When we asked the operator about this, they attributed it to the fact that we have been allocated less frequency spectrum compared to the available commercial solution, which leads to poorer performance. We have requested more data regarding the available spectrum, but we have not received as of the date of this deliverable.

Latency

Another shortcoming we see is regarding latency. In addition to the spectrum issue mentioned earlier, another contributing factor could be that the signal needs to travel all the way from the test facility in Trondheim to the core network in Oslo even when both communicating devices are located at the test facility. This distance is about 500 km and is likely an additional factor in the observed latency.

Range

The results of the range test were very positive. The lowest speed we could observe throughout the test facility was around 550 Mbps (see D4.2C for more details). This is significant due to the factory-like environment and the existence of metal objects all over the facility. Those results include testing with non line-of-sight locations and direct paths to the radio dots being blocked by metal objects.

3.3.5 Planning for the use case Post Project

The area of using 5G in smart factories has great potential beyond what we have demonstrated as part of our use case with 5G-Solutions . Unfortunately, we were not able to expand much on the functional side of the use case during the project period due to delays in the 5G-VINNI test facility and unavailability of some equipment.

The participating partners in use cases 1.3 and 1.5 have expressed interest in continuing to work on developing the test setup and running more advanced tests to utilize the low latency and high speed capabilities of 5G in the area of industrial automation.

In addition, as mentioned in D4.2C, we are continuing to work in integrating the Asset Administration Shell with CDSO and deploying it as an Edge App to allow for more flexible service orchestration of our application within the 5G network.

mmWave

In the last phase of LL1 Cycle 3, we have successfully installed a mmWave Street Macro node at the Manulab test facility in Trondheim. This node is connected to the 5G SA setup we have at NTNU and is connected to the 5G VINNI SA Core at Fornebu, Oslo. The purpose of this setup is to utilize the improved latency and bandwidth characteristics of mmWave 5G in industrial scenarios. This setup operates in NR-DC (New Radio - Dual Connectivity) configuration of the 5G Core, which uses 5G gNodeBs for both the master and secondary RAN nodes. UE support is required before the network can configure the UE with NR-DC configuration.

All the available commercial 5G modems in the market that we could find only support EN-DC (E-UTRAN New Radio – Dual Connectivity) configuration, which is not supported by our SA Core. We are currently in contact with some 5G equipment vendors regarding this and as of January 2022, they informed us that their 5G modules that support NR-DC are in their final testing phases and they should be able to provide us with units soon. Our hope is that during the coming few months we will be able to utilize this equipment to verify the functionality of the installed mmWave node and start using it with our project.

4 Conclusions and Next Actions

To achieve Cycle 3 trials, each of the Use Case owners has faced many difficulties in order to implement and upgrade each of the test beds in comparison to other Use cases and other living labs.

It is being clear that industry represents still a challenge for a certain telecommunication technology that is being normally demonstrated at lab scale or in a different environment, without the presence of long distances and lack of coverage due to a high amount of machinery.

The following points would be recommended to take in consideration for the future:

- *Despite the new 5G Technologies implemented in order to improve the KPI Requirements from UC1.1, the KPIS required for the use case has been partially achieved.*
- *UC 1.2 the trials has run successfully all trials, but no major involvement in the orchestration and VNF creation has been progressed.*
- *UC1.3 and UC1.5 has a great potential to become a reference case study for the application of the 5G using 5G VINI Infrastructure, but there is a need of alignment with local stakeholders and technology providers to provide a post project stable area of test in order to keep developing trials.*

As overall, conclusion, we can share that industry involvement during the project implementation has been great and the project has triggered investments on future technologies linked to 5G in order to keep promoting such technology. Further support on improving robustness of the equipment and coverage would be needed in order to satisfy the industrial KPI Requirements.